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Some Scientific Aspects of Packaging and Quick- Freezing Perishable Flesh Products¹

I—More Rapid Freezing Means Better Preservation

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IT IS the purpose of this article to contrast the characteristics of air-frozen and quick-frozen products. For present purposes air-frozen, slow-frozen, and sharp-frozen will be considered as synonyms referring to products frozen in modern "sharp freezers" with a minimum temperature of about 10° or 15° F. below zero (−23.33° or −26.67° C.). "Quick-frozen" will be used to designate products that have been frozen by direct immersion in a liquid refrigerant such as sodium chloride brine, or by indirect contact with a very cold liquid refrigerant such as calcium chloride brine.

Animal flesh is made up largely of countless elastic-walled cells filled with a semi-liquid protein gel. This gel contains a large percentage of water in which are dissolved appreciable quantities of sodium, calcium, potassium, magnesium, manganese, iron, and zinc salts in the form of chlorides, phosphates, sulfates, bromides, and iodides. Water in which these salts are dissolved does not freeze homogeneously. Instead, fresh water ice begins to freeze out of the cellular and intercellular material when the temperature of the product is lowered to about 31° F. (−0.56° C.), and, as the temperature is lowered still further, more and more fresh water ice is formed, leaving an ever more concentrated solution of the various salts. The water content of fish is not entirely frozen until the temperature of the flesh has been reduced to approximately −70° F. (−56.67° C.).

¹ Received February 8, 1929.

Percentage of Freezing at Various Temperatures

Complete figures are not available to show exactly what percentage of the moisture content of fish is frozen at various temperatures, but from the fragmentary evidence at hand it may fairly be inferred that a very large part has been solidified by the time the temperature has been lowered to 25° F. (-3.89° C.). From Figure 1, which shows the time required to thaw a fillet in the center of a filled 50-pound insulated shipping container, it will be noted that the temperature rise is very rapid from -10° F. (-23.33° C.) to 25° F. (-3.89° C.), the curve thereafter remaining comparatively flat until the temperature has reached about 31° F., after which it again shoots up very rapidly. Figure 2 shows that the time-temperature curve in sharp-freezing a carton of fillets is very much the same shape as that in Figure 1. Taylor² says that at 5° F.

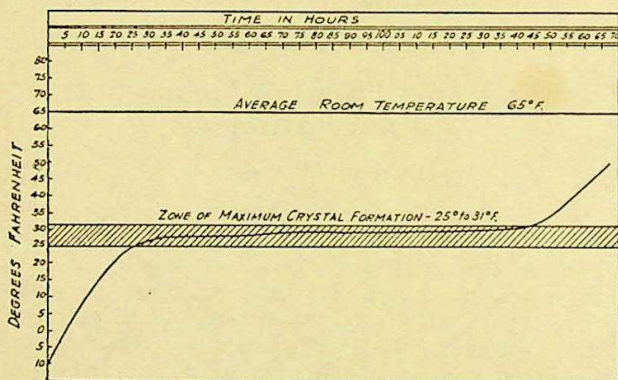


Figure 1—Temperature Rise during Thawing Period in Center Package of a 50-Pound Insulated Corrugated Shipping Container of Haddock Fillets

(-15° C.) about 15 per cent of the water remains unfrozen; while at 31° F. (35° C.) below zero, about 2.5 per cent remains liquid. Plank³ has ascertained that at 29.3° F. (-1.5° C.) only 42 per cent of the water is frozen; while the very last of the water, which is more closely bound to the muscle colloids than the rest, is not frozen until a temperature of at least 68.8° F. (57° C.) below zero is reached. These facts have been used in the preparation of Figure 3.

Crystal Formation

During the period in which the bulk of the moisture content is being frozen, the individual ice crystals are continuously increasing in size, by accretion. After the temperature has reached 25° F. (-3.89° C.), by which time most of the water has probably been frozen, the growth of individual

² Taylor, "Refrigeration of Fish," Appendix VIII to Report of U. S. Commissioner of Fisheries for 1926, p. 501, Washington, 1927.

³ Plank, *Z. ges. Kälte-Ind.*, 32, 141 (1925).

crystals apparently largely ceases. Therefore, we may for convenience refer to the temperature zone from 31° F. (-0.56° C.) down to about 25° F. (-3.89° C.) as the "zone of maximum crystal formation." And since, when substances crystallize, the size of the crystals depends upon the time allowed for them to form, it is obvious that the more quickly flesh is passed through this zone of maximum crystal formation the smaller the crystals in the frozen product will be.

In usual sharp-freezer practice fish is frozen in from 12 to 48 hours, the heat being removed from the surface principally by convection air currents. The heat transfer is so slow that moisture at the center of the fish begins to crystallize almost as soon as that near the surface, the whole mass of the fish gradually becoming first firm and then hard. From Figure 2 it will be seen that if a 2-inch (5-cm.) package of fresh fish requires 10 hours to freeze hard in a sharp freezer, a small

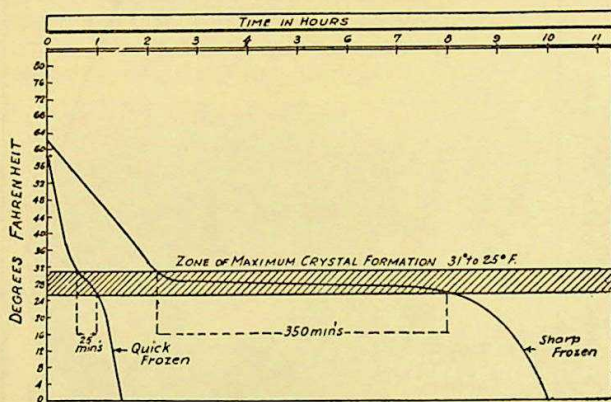


Figure 2—Time Required to Sharp-Freeze and Quick-Freeze in Center of a 2-Inch (5-Cm.) Carton of Haddock Fillets

group (about 1 cc.) of cells in the center of the package will require approximately 6 hours to pass through the zone of maximum crystal formation. It is thus evident that in sharp-frozen fish a great deal of time is allowed for the formation of large ice crystals, which are sometimes as much as an inch (2.5 cm.) in length.

Effect on Tissues

The formation of these large sharp-pointed ice crystals within and between the cells results in a more or less serious rupture of the more delicate of the tissues and a compression of the tougher and more resistant fibers into dehydrated layers or bundles.⁴ Moreover, this badly ruptured sharp-frozen flesh autolyzes more rapidly,⁵ and is more susceptible to bacterial decomposition than fresh undamaged flesh.

⁴ Cook, Love, Vickery, and Young, *Australian J. Exptl. Biol. Med. Sci.*, 3, 15 (1926).

⁵ Taylor, *Op. cit.*, p. 523.

During the comparatively slow process of sharp-freezing, a considerable amount of moisture is lost by evaporation from the surface.⁶ Exact figures on the amount of this loss are not available; but it probably averages from 1.5 to 4 per cent on fish frozen in blocks, 3 to 7 per cent on singly frozen fish, and 2 to 6 per cent on bulk-frozen meats.

When flesh products are quick-frozen by direct or indirect contact with a very cold liquid refrigerant, heat is extracted from them with such extreme rapidity that, instead of being chilled almost uniformly throughout their bulk, the freezing zone advances toward the center as a sharply defined line, on one side of which the flesh may be frozen hard while on the

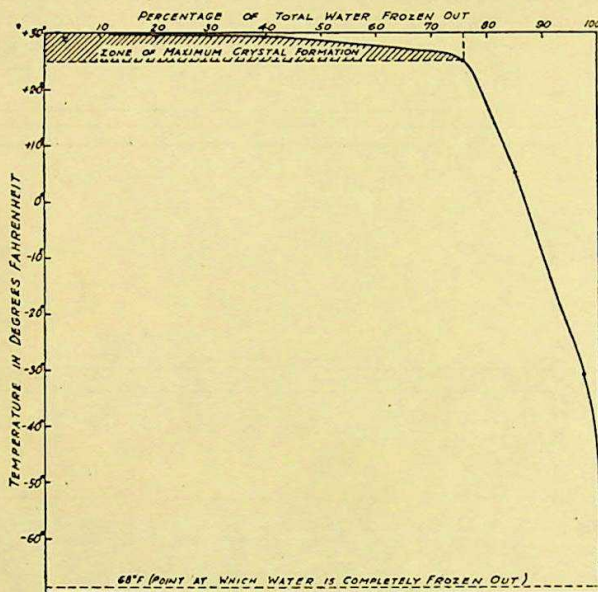


Figure 3—Percentage-Temperature Curve of Crystallization in Freezing Flesh Products

other crystallization has not commenced. By referring again to Figure 2 it will be noted that the package of fish which required 10 hours to harden in a sharp-freezer needed only 1½ hours to quick-freeze. The chart also shows that, although the whole package required 6.66 times as long to sharp-freeze as it did to quick-freeze, 1 cc. of tissue at the center of the quick-frozen package passed through the zone of maximum crystal formation in 25 minutes, or fourteen times as fast as in the sharp-frozen package.

Thus quick-frozen flesh is passed through the zone of maximum crystal formation so very rapidly that the resulting ice crystals are too small to be capable of materially rupturing or compressing the tissues. The contrast between sharp- and

⁶ Peterson, *Refrigerating World*, September, 1924.

quick-frozen flesh is clearly illustrated in Figure 4. *A* is a photograph of a piece of sharp-frozen haddock fillet cut "across the grain." This fillet was taken from near the center of a 30-pound tin of parchment-wrapped fillets of a well-known brand frozen in 36 hours in a large Boston plant. Even a casual glance at this illustration shows the serious damage done by the crystals. Much of the tissue was reduced to an amorphous mass which escaped at the cut surface when the product thawed. The remaining flesh has been compressed into tough bundles utterly incapable of re-absorbing the moisture from the melted crystals. Such a sharp-frozen piece of flesh spoils rapidly; and even when cooked immediately after being thawed, is dry, pulpy, lacking in nutrient value, and totally without the delicious flavor of the fresh product.

Figure 4-*B* shows a section of quick-frozen flesh from the center of a 10-pound package of haddock fillets. It is perfectly obvious that no large crystals were formed when this fish was frozen, and that no damage has been done to the flesh. Such a fillet, even though it may have been held in storage for several months, is still truly fresh fish.

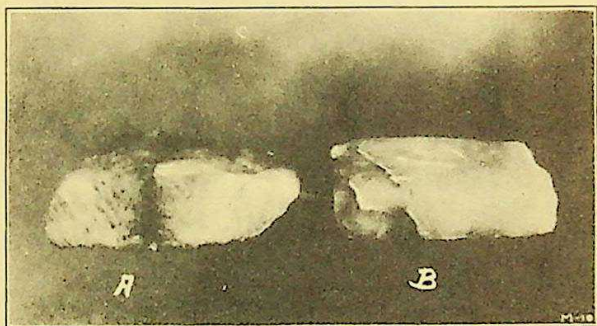


Figure 4—(A) Sharp-Frozen Haddock Fillet; (B) Quick-Frozen Haddock Fillet

Figures 5 to 10 illustrate microphotographically the damage which large ice crystals cause to individual cells of sharp-frozen haddock fillets and beef tenderloins. These photographs were taken under the supervision of R. P. Bigelow, of Massachusetts Institute of Technology. The cells of the fresh, unfrozen product are entirely normal in appearance; the quick-frozen cells show not the slightest damage from ice crystals; but the sharp-frozen cells are obviously badly ruptured. It is interesting to note that the sharp-frozen and quick-frozen haddock cells came from the fillets illustrated in Figures 4-*A* and 4-*B*, respectively.

Professor Bigelow made a further careful study of muscle tissue from fresh, sharp-frozen, and quick-frozen haddock fillets, and the following extract from his report is illuminating:

On examination, the fresh haddock appears to be well preserved. The structure of the muscle fibers is well seen, the

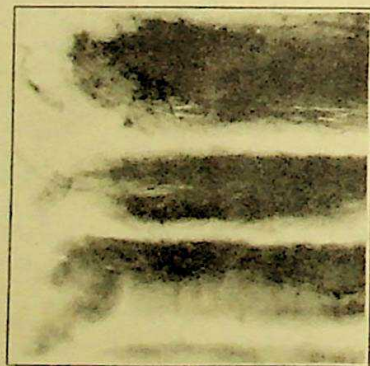


Figure 5—Cells of fresh unfrozen haddock. Note that the cells are perfect and have a full rounded appearance.

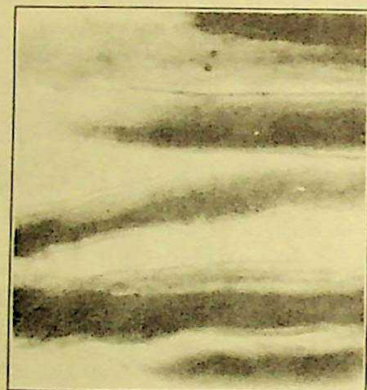


Figure 6—Cells from quick-frozen haddock. Note cells perfect in every way.

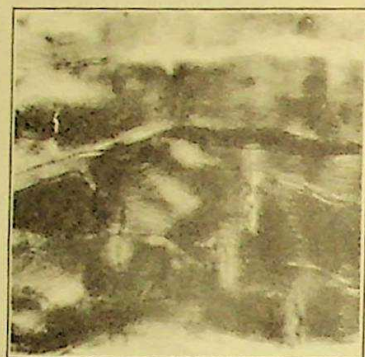


Figure 7—Cells from a haddock fillet frozen in the regular manner. Note ruptures caused by ice crystals and flat empty appearance of cells.

Haddock

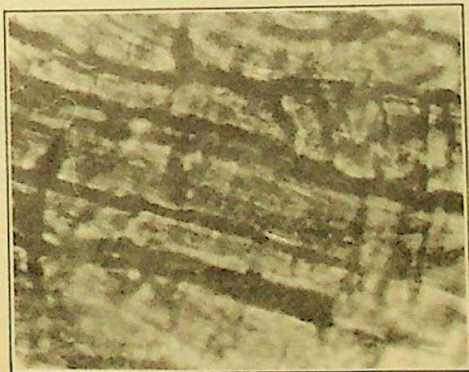


Figure 8—Cells from fresh unfrozen beef.

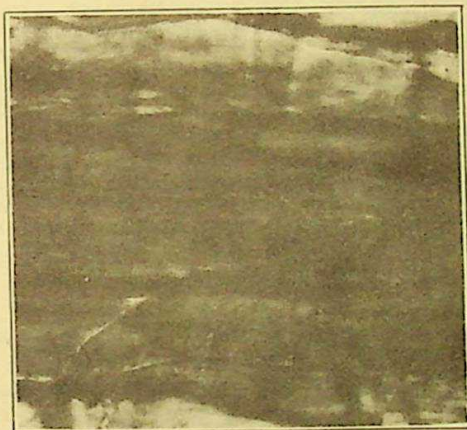


Figure 9—Cells from beef frozen in 30 minutes in quick-freezing apparatus. Note that cells are unbroken.

Beef Tenderloin

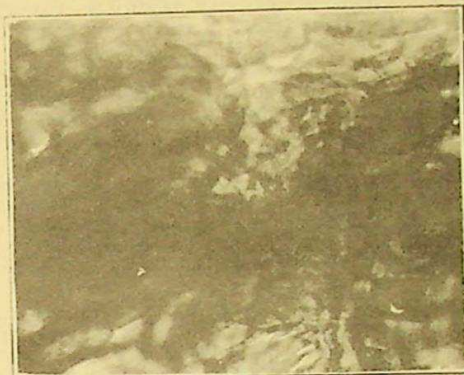


Figure 10—Cells from beef frozen by ordinary commercial cold-storage methods.

fibrillae being quite distinct and in places the striations are visible. Between the fibers is the connective tissue. Blood vessels and capillaries can be seen, containing nucleated blood corpuscles, and in several places very beautiful pictures are seen of nerve fibers showing clearly the axis cylinder and the sheath.

The quick-frozen haddock showed apparently some disintegration of the connective tissue between the fibers, probably due to a slight maceration during the handling between the death of the fish and the commencement of freezing. But in some places the nuclei of the connective tissue can be seen and the blood vessels show distinctly the nuclei in their smooth muscle fibers. The striated muscle fibers of the muscle appear to be in good condition, showing distinctly both the fibrillae and the cross striations. In this material, as well as in the fresh haddock, the nuclei within the muscle fibers are not very distinct.

The slow-frozen haddock has a very different appearance in cross section under the microscope, as well as when seen in the hand. The muscle fibers seem to be swollen. Together with the differences in size, these muscle fibers show very different structure. In the first place, they are firmly pressed together so that only a very narrow space appears between them, and they are not evenly distributed throughout the specimens as in the case of the fresh and the quick-frozen fish. Between these masses of pressed fibers were large empty spaces, or large spaces filled with an amorphous material which may be the result of the disintegration of connective tissue. The connective tissue seems to have entirely disappeared as such from the specimen. This makes it very difficult to prepare a block for section cutting, because as soon as one attempts to cut a small piece of the flesh it falls apart. I think these slides show a very big difference between the slow-frozen haddock on the one hand and the quick-frozen and the fresh material on the other.

Shrinkage

For obvious reasons, loss of weight by evaporation during quick-freezing by any of the better known methods is very much less than in sharp-freezing. When the products are properly protected by highly vapor-proof packages before being frozen, the shrinkage is negligible. At one large quick-freezing plant the average shrinkage in freezing haddock fillets wrapped in Moistureproof Cellophane and packed in 10-pound cartons is less than 0.25 per cent.

Table I shows that there was practically no shrinkage in various packaged dressed meat products experimentally quick-frozen at the above plant.

Table I—Loss of Weight during Quick-Freezing of Certain Packaged Meats

PRODUCT	BEFORE FREEZING		AFTER FREEZING	
	Lbs.	Oz.	Lbs.	Oz.
Sirloin steaks	11	4 1/2	11	4 1/2
Pork chops	5	12 3/4	5	12 3/4
Beef tenderloin	5	10 3/4	5	10 3/4
Lamb chops	5	12 1/2	5	12 1/2
Lamb kidneys	6	6 1/2	6	6 1/2
Calves liver	6	3 3/4	6	3 3/4

Other Advantages of Quick-Freezing

When certain forms of meats and poultry are sharp-frozen, the extensive drying of the surface, sometimes apparently as-

sociated with a partial oxidation of the fats in and immediately under the skin, causes an effect known as "freezer-burn," which considerably lowers the value of the products. Freezer-burn was entirely absent in the packaged meats considered in Table I, and did not occur even with such bulk products as green pork bellies frozen in direct contact with the metal belts of the quick-freezing apparatus. Perhaps equally important, from the marketing point of view, was the fact that the color and odor of the packaged meats was not changed at all by the quick-freezing. "Drip"—leakage of moisture from the product during the thawing process—was very slight indeed.